

Warning Time for Maximum Precipitation Events

1.0 Introduction

Local Intense Precipitation (LIP) is a hypothetical locally heavy rainfall event that is used to design flood protection features and/or procedures. LIP is typically assumed to be equivalent to the local probable maximum precipitation (PMP) derived from National Weather Service (NWS) Hydrometeorology Reports (HMRs) or from a site-specific PMP study. LIP estimates derived from the HMRs can, in some locations project rainfall in excess of 19 inches for 1-hour over one square mile. If a nuclear site's protection is not permanent and passive, a rainfall event of this magnitude may require actions to be taken prior to the storm to protect or mitigate flooding impacts on required structures, systems, and components (SSC's). As such, warning time is a key component in the planned response to the LIP or a consequential rain event.

Despite improvements in forecasting accuracy of precipitation, the present state of the meteorological science's tools and techniques are not able to reliably predict LIP events explicitly in time and space (Ralph et al. 2010, Olson et al 1995, Sukovich et al 2014). This is due in part to limitations in weather model capabilities and is also due to the limited frequency of extreme precipitation events. Yet, despite these limitations, forecasting tools are available to detect storms that could lead to extreme events to provide lead time to implement mitigation actions.

1.1 Basis for Methods - Recognizing the limitations in forecasting accuracy for extreme events, methods to establish warning time for maximum precipitation events are based on:

1. Recognition that maximum precipitation events that produce LIP level rainfall require both substantial atmospheric moisture and a sustained atmospheric lifting mechanism, which can be recognized and anticipated.
2. Setting warning thresholds conservatively based on less extreme (and more predictable) storms to assure that protection or mitigation can be executed prior to consequential flooding (see section 5.2.1 for a definition of consequential flooding).
3. Including additional conservatism to compensate for forecasting uncertainty by setting monitoring and trigger thresholds that are a fraction of the LIP precipitation level that would result in consequential flooding.
4. Evaluating local thunderstorms (thunderstorms or intense convective showers) for the nuclear site and confirming that assessing whether the maximum rainfall from a local thunderstorm will not produce is capable of producing consequential flooding for the site. A local thunderstorm is defined as an extreme rainfall event, not associated with widespread heavy precipitation, that produces rain for durations of 6 hours or less, and is concentrated over an area of 500 square miles or less (Riedel et al 1980).

Using existing forecasting tools and addressing known forecast limitations with conservative measures to compensate for uncertainty can provide an acceptable method for establishing warning time to implement flood protection or mitigation responses for maximum or consequential precipitation events.

Comment [S1]: General comments:

- **Title:** As written, the title could be misinterpreted to imply this paper applies to more than just local (site) precipitation. This title should be corrected to clarify that the scope is local precipitation. Change requested to remove ambiguity regarding application to basin-wide PMP events.
- **Terminology:** A number of terms such as "warning", "warning threshold", "monitoring", "monitoring threshold", "trigger", "trigger threshold" are used in this document. It's not clear what the distinction is between these terms. It is suggested that a smaller number of terms be selected/defined and used consistently throughout the text (rather than using multiple terms synonymously). For example, clarification is needed regarding whether 'LIP level' is the estimate of the most severe precipitation affecting the site (e.g., is this a synonym for Local PMP?).

Comment [S2]: That staff notes that maximum precipitation events may not be recognized/anticipated due to limitations in numerical models. Moreover, it is noted that this paper is concerned primarily with consequential rainfall amounts rather than maximum amounts. Is the following text what was intended?

Recognition that ~~maximum extreme~~ precipitation events ~~that produce LIP level rainfall~~ require both substantial atmospheric moisture and a sustained atmospheric lifting mechanism, which can be recognized and anticipated. It is noted that consequential precipitation events may occur with less substantial atmospheric moisture and lifting than maximum precipitation events.

Comment [S3]: This statement implies that the "base" position is that local thunderstorms are not capable of producing consequential flooding and that this assumptions simply needs to be confirmed. Instead, staff proposes to edit the statement as shown since the staff does not find technical support for a generic statement that local thunderstorms should not have capability to produce consequential flooding.

2.0 Relationship Between Local Intense Precipitation (LIP) and Probable Maximum Basis for Local Intense Precipitation (LIP) Maximum Precipitation Events

NUREG/CR-7046 recommends that LIP events can be based on the 1-hr, 2.56-km² (1-mi²) PMP at the location of the site. Some sites may need to consider longer duration events if they result in higher water level elevations than the 1-hr event. However such an analysis, if performed, should still include a maximum 1 hour rainfall within the assumed duration. NUREG/CR-7046 also recommends the use of the most recent hydrometeorological (HMR) report unless an approved site-specific PMP (or HMR) study is available. PMP is defined as, “theoretically the greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographical location at a certain time of the year” (Hansen et al., 1982). For most nuclear sites east of the 105th meridian, the current HMR’s are: HMR-51 (all season PMP values), HMR-52 (application guidance), and HMR-53 (seasonal guidance). The National Weather Service also has HMR’s for west of the 105th meridian which can be accessed from their website (<http://www.nws.noaa.gov/oh/hdsc/studies/pmp.html>).

3.0 Sources of Maximum Precipitation Events

The highest recorded worldwide one hour rainfall event is 15.79” in Shangdi, Inner Mongolia, China in 1975. The highest recorded US rainfall event approaching 1 hour occurred in Holt, Missouri in 1947 with 12” of rain in 42 minutes. The highest estimated 1 hour event occurred in Burnsville, West Virginia in 1943 with an estimated rainfall of 13.8” (NOAA.gov “Record Point Precipitation Measurements for the World and the USA”). It has also been shown that there are several instances in which PMP has been exceeded by or are very close in magnitude to observed events (Harrison 2006). Storms that have the potential to deliver rainfall that approaches or exceeds the maximum rainfall projected by the HMR would be detectable in advance with current forecasting methods/models based on the anomalously large amount of moisture and level of atmospheric instability (lift) required to generate precipitation of this magnitude.

Local thunderstorms should not have the capacity to produce LIP or consequential rainfall for the site (This must be verified for each site. See Section 1.1 Item 4) because of the short duration of sustained lift, lack of moisture, and transient nature.

General storms that have the potential to produce LIP magnitude or consequential rainfall events would be detectable in advance utilizing current forecasting methods/models. The large weather systems capable of producing LIP or consequential rainfall include:

- Tropical Systems
- Synoptic Storms
- Mesoscale Convective Complexes (Organized Thunderstorms)

These three basic storms types (including combinations of these storms) are briefly described below along including a discussion on the contribution of orographic effects.

3.1 Tropical Systems

This storm type includes warm core systems with origins over the tropical waters of the Atlantic Ocean or Gulf of Mexico (including the Caribbean Sea). It should be noted that on rare occasions modified tropical cyclones have made landfall over California and far southern Arizona (e.g. tropical cyclone Nora which arrived in Arizona in 1997 as a tropical storm). Tropical systems can produce PMP and LIP level rainfalls as well as consequential rainfall. Moreover, in these locations in a modified form where these rainfall events can also occur as the storm has begun to transition into an extra tropical storm.–

Comment [S4]: It is important that the notion of “most severe” be related to flood height, associated effect, and flood event duration. It is suggested that this sentence be changed as follows:

Some sites may need to consider longer-different duration events if they result in higher-water-level elevations more severe flooding (e.g., higher flood height, more severe associated effects, or longer period of inundation) than the 1-hr event.

Comment [S5]: NRC staff has concerns that this sentence contains a certain/unequivocal statement that is not supported by research/statistics. Staff notes that maximum precipitation events (including timing, location, and depth) may not be recognized/anticipated due to limitations in numerical models. Is it instead intended that these statements apply to the conditions associated with storms rather than the specific consequences of the storm?

Moreover, this paper is concerned primarily with consequential rainfall amounts rather than maximum amounts. Is this statement intended to apply to events that “approaches or exceeds... the HMR” or rather events that are consequential to the site?

Comment [S6]: The staff does not find technical support for a generic statement that local thunderstorms should not have capability to produce consequential flooding. What is intended by this statement?

Comment [S7]: Staff notes an internal inconsistency in this paragraph. Specifically, this paper recognizes LIP occurring from 1-hour events. Section 1.1, item 4 defines a t-storm as a 6-hour event (which is >1hr). Section 3.0 then states that t-storms (which are defined as up to 6hrs) can't produce LIP events because they are too short in duration.

Comment [S8]: NRC is concerned that the certain/unequivocal statement here regarding detectability of the specific characteristics of “large” general storms is not supported by research/statistics or available numerical models. Is this statement intended to reference the conditions associated with storms rather than the specific consequences of the storm? For example, is the following what was intended?

Conditions associated with general storms that have the potential to produce LIP magnitude or consequential rainfall events would may be detectable in advance utilizing current forecasting methods/models. However, timing, location, and depth of precipitation (i.e., rainfall amount) associated with these events may not be accurately forecasted.

High levels of tropical atmospheric moisture can produce extreme rainfall, especially when enhanced by convection/thunderstorms and slow movement.

3.2 Synoptic Storms

This storm type includes large scale frontal systems created by the interface between contrasting air masses. Synoptic storms can occur at any location across North America. These occur most often in the winter along the Gulf Coast and southern/mid-Atlantic region and along the West Coast. This pattern shifts northward through the spring and summer, before shifting south again in the fall. This is directly related to the climatologically preferred region of the jet stream (polar and sub-tropical). Synoptic storms are not typically capable of producing LIP level rainfall. However, the frontal systems associated with synoptic storms can include imbedded convection in the form of thunderstorms. These thunderstorms when related to strong synoptic scale events like deep mid-latitude low pressure systems or intense cold fronts can produce heavy rainfall due to atmospheric instability and dynamic lifting. In rare cases rainfall amounts associated with this form of large scale frontal systems with embedded thunderstorms could produce a LIP event or a less significant event with consequential rainfall if the system moves slower than normal, especially if there is some additional form of topographic or synoptic enhancement to the updraft.

Remnants of tropical storms can interact with synoptic storms, especially slow-moving storm systems, and produce large amounts of rainfall. PMP level rainfalls are possible in these situations. The weather forecasting community including the NWS has long recognized this set-up as a “classic” heavy rainfall and flooding situation and therefore anticipates these events well in advance with current forecasting models.

3.3 Mesoscale Convective Complexes

A Mesoscale Convective Complex (MCC) is an organized group of thunderstorms over a spatial scale larger than individual thunderstorms, but smaller than synoptic-scale storm systems. These systems can occur at any location across North America, but are much more likely in regions away from the stabilizing effects of the cool waters of the Pacific Ocean. These storms are most common in the spring through early fall, though they are possible in the winter months as well. MCC development is directly related to availability of atmospheric moisture which is usually supplied by a low-level jet stream feature and lift through a significant portion of the atmospheric column (instability). The atmospheric lift is enhanced through thermodynamic or dynamic processes or a combination of both. Typically, these systems move quickly, helping to limit extreme rainfall amounts. However, this storm type can produce rainfall that can approach LIP levels. Excessive amounts of rainfall associated with MCCs will most typically occur when the system is moving very slowly producing large amounts of rainfall within heavy downpours.

3.4 Orographic Effects

Orographic effects can mechanically produce the constant atmospheric lift to generate extreme precipitation in the absence of a synoptic scale event or mesoscale convective forcing. This occurs when terrain (e.g. located in or near mountainous regions) serves as an immovable source of lifting which is the key in enabling an extreme precipitation scenario. Examples where strong orographic lift contributed to three extreme MCC precipitation events include Smethport, PA - 1942, Central West Virginia – 1943, and Simpson KY – 1939. Orographic effects have the potential to reduce warning time.

4.0 NOAA/National Weather Service Severe Weather Forecasting and Notification Tools— The National Weather Service (NWS) has central national monitoring and local branches that monitor developing weather conditions to detect and provide warning for severe weather prior to its arrival. There are a number of different forecasting tools and services for severe rain events provided by

Comment [S9]: It is not clear what is meant by “modified tropical cyclone” or “modified form” in this paragraph. This paragraph is also not clear that tropical storms as well as those transitioning to extra-tropical events can produce local PMP level rainfall. Moreover, this paragraph focuses on “maximum rainfall amounts” whereas this white paper is concerned primarily with consequential rainfall amounts rather than maximum amounts. Some edits were made to the text. Was this what was intended?

Comment [S10]: Staff notes that this paper is concerned primarily with consequential rainfall amounts rather than maximum amounts. As a result, the NRC is concerned this statement may be understating the importance of considering this type of event. Is the following what was intended?
Synoptic storms are not typically capable of producing LIP level rainfall, but may produce consequential flooding.

Comment [S11]: Much of the information in Section 4 appears to duplicate <http://www.hpc.ncep.noaa.gov/html/fam2.shtml>. The staff notes that the information in this web site is updated periodically. Importantly, the weather products/services frequently change (e.g., publication of PQPFs is a relatively recent service). This could impact the reports relied upon to implement the guidance in Section 5. Therefore, the white paper should instruct users of the guidance to periodically review the available weather reports and update the plant-specific triggers accordingly. The white paper should include a reference to the above web site or other sources.

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the NWS. The recommended tool for a warning time trigger is a quantitative precipitation forecast which provides a specific amount of rain for a given time period. Additional tools are also discussed below which can be used to provide supporting information on the basis for the rainfall amount being forecasted.

4.1 Excessive Rainfall Forecast—The NWS Weather Prediction Center (WPC) Products: The WPC mission is to forecast the potential for significant weather events dealing with heavy rainfall or snowfall, to discuss precipitation forecasts and model differences relating to general weather and precipitation forecasts. The WPC issues several focusing tools such as: Quantitative Precipitation Forecasts (QPFs), Probabilistic Quantitative Precipitation Forecasts (PQPFs), and Excessive Rainfall Outlooks.

The WPC short range meteorologist prepares 6 through 60 hour forecasts for the continental U.S. These products are issued twice daily using numerical model output from the National Weather Service's (NWS) Global Forecast System (GFS) and North American Mesoscale model (NAM). Coordination with the surface analysis, model diagnostics, quantitative precipitation, winter weather, and tropical forecast desks is also performed during the forecast process. The short range forecast products include surface pressure patterns (isobars), circulation centers and fronts for 6-60 hours, and a depiction of the types and extent of precipitation that are forecast at the valid time of the chart. The primary goal is to depict accurately the evolution of major weather systems that will affect the continental U.S. during the next 60 hours. In addition, discussions are written on each shift and issued with the forecast packages that highlight the meteorological reasoning behind the forecasts and significant weather across the continental United States. Precipitation levels are not included on the 60-hour forecast chart

4.1.1 Quantitative Precipitation Forecasts (QPF) – QPF's depict the amount of liquid precipitation expected to fall in a defined period of time (e.g. forecast of total rainfall for 6, 12, 24, and 48 hour periods). In the case of snow or ice, QPF represents the amount of liquid that will be measured when the precipitation is melted. Precipitation amounts can vary significantly over short distances, especially when thunderstorms occur. For this reason QPFs issued by the WPC are defined as the expected "areal average" (on a 20 x 20 km grid) in inches. –Methods for producing QPFs are similar to other meteorological forecasts. First, meteorologists analyze the current state of the atmosphere. Then they use model forecasts of pressure systems, fronts, jet stream intensity, etc., to form a conceptual model of how the weather will evolve. The WPC has unique access to the full suite of operational and ensemble model guidance from modeling centers in the U.S., Canada, and Europe (the foreign models are global models, so they also make predictions over the U.S.). The WPC stores output from several consecutive runs of all of these models, allowing for trend analysis of model QPFs.

WPC forecasters often engage in discussion with the local National Weather Service Forecast Offices (122 locations), River Forecast Centers (12 locations) in the Continental United States), and other national centers such as the Storm Prediction Center and National Hurricane Center. The WPC provides the rainfall forecast (known as a rainfall statement) that the National Hurricane Center inserts into each tropical cyclone advisory it issues. The WPC is also co-located with NOAA's National Environmental Satellite, Data, and Information Services (NESDIS) Synoptic Analysis Branch (SAB). The SAB provides information on satellite trends which helps refine short range QPFs. Together, the SAB and Day 1 QPF desk at the WPC are known as the National Precipitation Prediction Unit (NPPU). This collaborative process makes WPC forecasts generally more accurate than any individual model (see section 5.2.3 Forecasting Accuracy Limitations).

Comment [S12]: It is noted that the QPF forecasted value may under-predict the magnitude of maximum precipitation for a nuclear power plant site due to grid resolution (i.e., use of an areal average on a 20km by 20km grid). This is also related to earlier comments regarding the differences between predicting "conditions" that may lead to consequential flooding versus predicting actual events (e.g., timing, location, depth).
How will this be addressed in the white paper?

The QPF contours (isohyets) are drawn to encompass areal average amounts of 0.01, 0.25 inch, 0.50 inch, 1 inch, 1.50 inches, and 2.00 inches (see Attachment 1). Any values greater than 2.00 inches are drawn in one-inch increments. In addition, the location of QPF maxima are indicated on the chart by an "X", with the associated maximum value printed underneath. It is important to note the valid time period when viewing each product. Specifically, for the Day 1, 2, and 3 forecasts, QPFs are manually created for 6-hour periods and an accumulated 24-hour total QPF is also issued. For the Days 4/5 and Day 6/7 QPF, forecasters manually create a 48-hour accumulation of areal average rainfall. Computer programs then take advantage of model forecasts of the timing of precipitation to break the WPC forecast down into 6-hourly QPFs.

4.1.2 Probabilistic Quantitative Precipitation Forecasts (PQPF) - The WPC produces 6-hour QPF's for forecast projection days one through three at 6-hour intervals (72-hour duration). Deterministic forecast models, including the National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS), the NCEP North American Mesoscale (NAM) model and the global model from the European Centre for Medium-Range Weather Forecasts (ECMWF), along with the NCEP Short-Range Ensemble Forecast (SREF) system produce forecasts covering this time period. These model runs constitute an ensemble from which uncertainty information is obtained to construct a probability distribution about the WPC QPF. This distribution is utilized to generate probabilistic forecasts of precipitation. The 6-hour QPFs are summed to obtain 24-h QPFs, which are the basis for 24-h probabilistic QPFs (PQPF's) generated using the same multi-model ensemble and the same method as for the 6-h probabilistic QPFs. The probabilistic QPF forecasts provide information in two different forms (see Attachment 1 which shows the tab selected for Precipitation Amount by Percentile for the 95th Percentile of a 24 hour forecast period):

- Probability of Precipitation of at Least a Specific Amount show filled contour levels of probability that the 6 or 24-hour accumulation of precipitation will equal or exceed the given threshold.
- Precipitation Amount by Percentile show filled contour levels of precipitation amount associated with a given probability percentile in the distribution with a range of values from the 5th to 95th percentile for 6 or 24-hour accumulation.

4.1.3 Excessive Rainfall Outlooks - The Excessive Rainfall Outlooks provide a forecast of the risk of flash flooding across the continental United States. A closed contour with an arrowhead delineates the probability forecasts, with risk areas defined to the right of the direction of the arrowhead. The probability categories are based on calibration studies conducted at WPC. The calibration for the excessive rainfall graphics are based on the frequency of events for which observed rainfall exceeded flash flood guidance values for a given risk category. When forecasters outline risk areas they are expecting greater organization of excessive rainfall than would be observed under average conditions. As confidence of excessive rainfall increases the category respectively evolves from Slight to Moderate to High. Day-1 Excessive Rainfall Outlooks (graphic and associated discussion) are issued four times per day: 03, 06, 15, and 18 UTC. Day 2 and Day 3 excessive rainfall forecasts are issued only twice per day. Flash Flood Guidance values incorporate soil type, land coverage, and a host of other factors in an attempt to describe the rain rate necessary to yield significant surface runoff and flash flooding over a given area. The River Forecast Centers issue guidance values for 1-, 3-, and 6-hour periods. Flash Flooding is considered to be caused by rainfall occurring in 6 or fewer hours, whereas longer duration rainfall represents areal flooding or inundation. The WPC excessive rainfall products focus specifically on flash flooding.

4.2 Mesoscale Precipitation Discussions

The WPC provides short term guidance to the National Weather Service (NWS) Weather Forecast Offices during heavy rain events when there is a threat of flash flooding. These are also provided to the media, emergency managers and interested partners. Guidance is given in the form of Mesoscale Precipitation Discussions (MPDs), that are issued 1-6 hours ahead of time. Each MPD consists of a graphic indicating the area of concern and any pertinent meteorological features as well as a brief text discussion focused on the mesoscale features supporting the anticipated heavy rainfall.

4.3 Tropical Public Advisories

The WPC will issue tropical public advisories after the National Hurricane Center (NHC) discontinues its advisories on subtropical and tropical cyclones that have moved inland, but still pose a threat of heavy rain and flash floods in the conterminous United States or adjacent areas within Mexico which affect the drainage basins of NWS River Forecast Centers. The last NHC advisory will normally be issued when winds in an inland tropical cyclone drop below tropical storm strength, and the tropical depression is not forecast to regain tropical storm intensity or re-emerge over water. WPC advisories will terminate when the threat of flash flooding has ended.

4.4 Local Precipitation Climatological Studies

Local NWS offices often produce local climatology studies which focus on specific forecasting problems in the NWS office's specific county warning responsibility area. Some of these studies focus on precipitation forecasting and contain results based on years of accumulated knowledge of local climatology. These studies may be available from the internet, or upon request from the local NWS office. Local NWS forecasters often cite results from these local studies as part of their daily forecast discussions. Forecast discussions from local NWS offices are available on the internet. Results of local studies, and the additional comments provided by local NWS forecasters in the forecast discussions, can be quite useful when assessing potential and actual heavy rainfall situations for specific locations.

Comment [S13]: Staff notes that these reports produced by the NWS local office are usually cited as "preliminary" until they are reviewed by the NCDC. Moreover, reports produced by the NWS local office are usually cited as "preliminary" until they are reviewed by the NCDC. Therefore, these are not useful for real time forecasts (i.e., as suggested by the last sentence that references "actual" heavy rainfall situations) but may be useful for understanding site-specific considerations (i.e., historical and potential heavy rainfall situations). Is it the intent to use these studies in evaluating site-specific triggers rather than as a forecasting tool?

4.5 Severe Weather Forecast Process - The NWS Storm Prediction Center (SPC) employs meteorological forecasting tools and models to generate severe weather forecasting notifications. The Storm Prediction Center receives input from the WPC on excessive rainfall that could lead to flash flooding for severe weather forecast and warnings. SPC Forecast and Discussions are intended for use by qualified personnel such as state, local or commercial meteorologists. Forecasts provided include:

Day 4-8 Severe Weather Outlook - graphic and text issued daily

Day 3 Convective Outlook - issued daily

Day 2 Convective Outlook - issued twice daily

Day 1 Convective Outlook – narrative and graphics with timing and severity, issued 5 times daily

- Flash flooding watches – issued with projection for time, location, and rainfall amount

Comment [S14]: The staff notes that the Convective Outlooks for Days 1-3, in addition to the Day 4-8 Severe Weather Outlook, on the SPC website depict non-severe thunderstorm areas and severe thunderstorm threats. They are probabilistic forecasts depicting risk levels for tornadoes, damaging winds, and large hail. These products are not directly linked to flooding. There may be write-ups of potential flooding events in their synoptic or mesoscale discussions that accompany these outlooks but that is not the purpose of these products. What is the intention of using this product in the context of this white paper?

5.0 Rain Event Trigger & Warning Time

Maximum rainfall events based on synthetic storms cannot be reliably forecast using current models and forecasting methods which were developed and validated based on historical rainfall. However, warning time for maximum precipitation events (or consequential rainfall) can be established based on less extreme events that occur infrequently but still fall on the high end of normal rain events. These high precipitation forecasts include the general storms systems that contain enough moisture for maximum or consequential rainfalls without relying on the capability to accurately forecast maximum

Comment [S15]: It is not clear what is meant by this statement, specifically the meaning of "synthetic storm." For example, is this intended to mean a "design storm" such as the PMP event arising from application of the HMR?

precipitation rainfall levels. This approach establishes monitoring and triggers based on less extreme events that will bound the maximum precipitation LIP event. Locations without terrain that can produce orographic lift can support the longer warning time due to the significant size of the storms required to produce precipitation approaching the maximum LIP or consequential rain event.

Rain event triggers and warning time mechanisms can be developed based on the time needed to implement any flood protection or mitigation measures. Notification levels can be established using a single trigger or multiple triggers. Multiple triggers can be established if the response to an extreme rain event is done in graduated steps (e.g. stage equipment at 48 hours, assemble equipment at 12 hours, and complete implementation at 6 hours).

5.1 QPF Forecast for Monitoring and Triggers:

Medium Range Forecast (monitoring threshold)

Days 4-7 –QPF forecast are issued twice a day with valid periods of 48 hours

Day 3 – QPF and PQPF forecast are issued twice a day with valid periods of 24 hours

Short Range Forecast (action trigger)

Day 2 – QPF and PQPF 6 and 24 hour forecast are issued twice a day (WPC forecast model updates every 6 hours) with a valid period of 24 hours. Additional information that can be used to supplement the PQPF include Excessive Rainfall Outlook (ERO) forecasts and event driven updates. Excessive Rainfall Outlook forecast are issued twice a day with a valid period of 24 hours.

Day 1 - PQPF forecast are issued twice a day at 0600 and 1800 UTC (Coordinated Universal Time) with a valid period of 24 hours.

Other Monitoring Data Sources include: (NWS) Storm Prediction Center, National Hurricane Center, local National Weather Service Forecast Offices (122 locations nationally), internal licensee meteorologist, and private weather forecasting consulting organizations.

5.2 Warning Time & Trigger: A method to establish warning time for maximum or consequential rain events can be established using NWS forecast tools. Warning thresholds should be set conservatively based on less extreme (and more predictable) events to assure that time is available to implement flood protection or mitigation measures prior to site specific consequential flooding (see 5.2.1 below) occurring. The warning time required should account for the time needed to implement flood protection or mitigation measures (e.g. closing doors, installing stop logs, staging equipment, etc) and take into account other conditions (e.g. wind, lightning, personnel availability) that could impact the time required to execute the mitigating actions.

5.2.1 Consequential Flooding: Consequential flooding may occur prior to the peak LIP flooding level (see Figure 1). Consequential flooding is the point at which flooding rises above the current flooding barriers (e.g., walls, door sills, flood gates, etc) such that SSCs important to safety are not impacted.

Comment [S16]: It isn't clear what is meant by this statement. Staff observes that less extreme events do not bound the maximum LIP event as stated in this section. Does this statement intended to say the following?

This approach establishes monitoring and triggers based on less extreme events that will bound the that are smaller than the maximum precipitation LIP event and more reliably forecasted.

Comment [S17]: The definition addresses consequential flooding but does not "link" it to the term "consequential rainfall" (i.e., rainfall amount capable of leading to consequential flooding), which is used throughout the document.

Comment [S18]: It is not clear what is meant by "current flooding barriers." The staff currently interprets this sentence to mean that consequential flooding is flooding that results in water levels above the permanently-installed flood barriers that prevent damage to SSCs important to safety. If so, it is important to differentiate between permanently-installed flood barriers that are passive vs. those that require actions by plant personnel (e.g., sills vs. flood gates) when defining the threshold for "consequential flooding." For example, is the following true?

"Consequential flooding is ... flooding rises above installed flooding barriers that are permanently in place and do not require any action by plant personnel (e.g., walls, door sills, flood gates, etc.)"

In addition, it appears this definition includes a spurious "not." Is it intended that consequential flooding be defined as a point in which SSCs important to safety are **not** impacted, as suggested by this sentence?

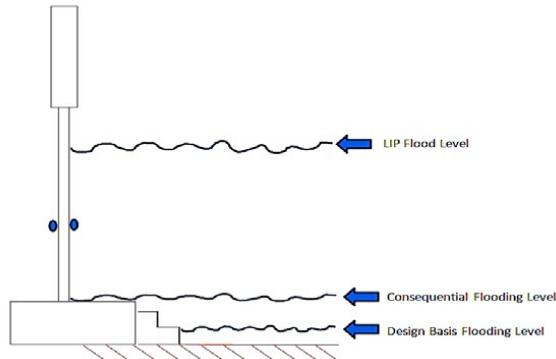


Figure 1. Consequential Flooding Illustration

5.2.2 Monitoring and Action Triggers: Warning time should be based on the storms (Tropical, Synoptic, and Mesoscale Convective Complexes-) that can produce the maximum or consequential rainfall for a given nuclear site location. This assumes that local thunderstorms (see definition in Section 1.1) have been evaluated for the nuclear site and it has been confirmed that the maximum rainfall will not result in consequential flooding for the site. Mesoscale convective complexes for sites with local terrain that can provide orographic lift, may have the shorter warning times. A meteorologist can determine what storm types apply to a given location including whether terrain has the potential to produce orographic lift. An acceptable method that provides a conservative warning time is to establish a Monitoring Threshold followed by an Action Trigger. This approach can be developed as follows:

- A. **Select a forecasting tool:** The recommended precipitation forecasting tools are the NWS QPF and PQPF as described in section 4.1. For the Monitoring Threshold use the NWS QPF for monitoring during medium range forecast from Day 3 to Day 7. For the Action Trigger, use the NWS PQPF (selecting the 95th Percentile forecast) for short range forecast for Day 1 and Day 2. The PQPF can also be used for both the Monitoring Threshold and the Action Trigger if desired.
- B. **Establish a Monitoring Threshold:** a monitoring threshold should be set by establishing a level of extreme rainfall for the basin where the nuclear facility is located. For most locations east of the 105th meridian a value of 2.0 to 3.1 inches in 24 hours would be considered an extreme rainfall based on a threshold of 0.01 frequency (the top 1% of days with rainfall) (Ralph et al 2010). See Ralph et al 2010 for 0.01 frequency extreme rainfall values that apply to the specific region where the nuclear site is located. This threshold should be set using the medium range forecast 3 to 7 days prior to the event. If this threshold still is met based on short range forecast on Day 2, the nuclear site would be notified (unless an earlier notification is ~~desired~~ **required based on site-specific factors such as time required for flood protection implementation**). ~~which~~ This would initiate site monitoring once per shift as directed by site procedure. Notification to the site should be provided by either internal meteorological services or by external contract meteorological services as long as the meteorological coverage is provided seven days a week and the notification process is formalized.

Comment [S19]: Please clarify whether forecasting tool is proposed as being applicable to all sites, or whether this is just an example.

If these are the proposed tools for all sites, are there limits on their applicability/acceptability with respect to site location or other flood-protection considerations (e.g., rainfall characteristics that would lead to consequential flooding, thresholds, time to implement corrective actions)? How would licensees tailor the triggers to account for plant-specifics?

NEI has previously mentioned that, in selecting weather products (for use in developing plant procedures/triggers), some licensees practices included a documented exchange between the licensee and the local forecasting offices from the NWS or similar organization. This seems to allow an understanding of the reliability of products and their capabilities in light of site-specific considerations (e.g., time required for implementation of protective actions). Is there an intention to document this "best practice" in the white paper?

Comment [S20]: Depending on the threshold selected, there may be a low probability of detection associated with the QPFs. In these cases, alternate products (e.g., convective outlook on conditions in the area) should also be considered for specifying monitoring thresholds, in addition to the QPFs. Monitoring should be initiated based on *either* the results of the QPF or the alternate tool (e.g., convective outlook).

Additional requested changes included in the text.

C. **Select an Action Trigger:**

1. An action trigger should be set at ½ of the maximum 1 hour LIP rainfall amount that requires protection or mitigation measures to be put in place. For example if a site’s maximum LIP is determined to be 18” but the site specific consequential flooding occurs with an 8” per hour rain event, the action trigger would be set based on the more limiting event at 4”.
2. This trigger value from a 1 hour rainfall event should be applied to a 24 hour rainfall projection based on the Day 1 or 2, 95th Percentile PQPF. The 1 hour LIP (or consequential flooding) used in developing the trigger should be based on the site specific LIP or consequential rainfall for the nuclear site using the appropriate HMR (e.g. HMR-52, or an approved site-specific study).

Based on the desired warning time, the 95th Percentile PQPF can be selected from the 24 hour short range forecast on Day 1 or Day 2. The 95th Percentile PQPF is recommended over the QPF for a Day 1 or Day 2 trigger to compensate for uncertainty by including probability distribution. When this trigger is reached, action would be taken to put protection or mitigation measures into place. Multiple triggers can be established if the response to an extreme rain event is done in graduated steps (e.g. stage equipment at 48 hours, assemble equipment at 12 hours, and complete implementation at 6 hours)

Alternate Action Trigger: If the return rate for ½ of the theoretical consequential flood is too high (i.e. results in excessive false triggers), an alternative approach can be used based on historical storms for the drainage basin where the site is located.

Conduct a search of historical storms within the drainage basin where the site is located to determine the historical storm with the maximum one hour rainfall. The maximum historical storm should have an annual exceedance probability of at least 1/100. If a 1/100 year or more historical storm has not occurred within the drainage basin, use additional historical storms from a region determined to be transpositionable to the location. The transpositioned storm would be centered on the location of the nuclear site, with appropriate adjustments for differences moisture and elevation between the original storm location and the nuclear site accounted for. The maximum one hour rainfall amount would then be evaluated to verify that the rainfall amount was not consequential for the site. If the one hour rainfall is not consequential, apply the one hour maximum rainfall value as the action trigger value for the 24 hour PQPF. For example, the maximum storm in the region delivered 16 inches over a two day period and the maximum 1 hour rainfall within that period was 5 inches. The annual exceedance for the storm was calculated to be 1/200 and it was determined that 5 inches of rain in one hour would not be consequential rainfall for the site. The 24 PQPF rainfall trigger would be set at 5 inches for the site. See the *Alternate Action Trigger Flowchart* located in Figure 2 below.

Comment [S21]: This write up is not clear (to the staff) about how the action trigger will be developed. This is due in part to the potential for consequential flooding being caused by a variety of rainfall events. Moreover, this section does not specify that selection of the action trigger should consider the time required to implement flood protection/mitigation at the site (e.g., if greater than 24 hours is required to implement flood protection).

One interpretation that the staff would find acceptable is as follows:

I. Define consequential rainfall depth: The licensee determines the smallest precipitation amount that, when distributed over one hour, may lead to consequential flooding at the site (e.g., as determined by hydraulic analysis). Consideration should also be given to whether precipitation amounts different than the above values may be consequential to the site and more limiting (e.g., brief but high-intensity rainfall events or prolonged lower-intensity events).

II. Define Trigger Value: The “trigger value” is set at the minimum of the following:

- one-half of the consequential rainfall depth (amount)
- one-half of the 1hr local PMP
- the saturation point of the PQPF (i.e., the largest rainfall amount considered by the PQPF; as shown in the figure below, this is 9 inches of rainfall)

III. Define conditions to initiate actions: Actions are initiated when the Day 1 or 2 (or longer depending on time required for plant response) 95th percentile PQPF projects cumulative rainfall amount greater than the trigger value over the next 24 hours.

Comment [S22]: It is not clear how consequential flooding is related to the HMR; therefore, recommend deletion of last phrase in last sentence of item (2)

Comment [S23]: The use of the Alternate Action Trigger removes conservatism and could result in trigger levels approaching the consequential rainfall level. Therefore, staff does not currently support this definition of an alternative action trigger. If the number of “false positives” is expected to be too high, licensees can propose alternative triggers on a plant-specific basis for staff review.

Staff also notes a sign error for AEPs in both the text and figure (e.g., AEP = 1/200 vs. recurrence interval = 200 years).

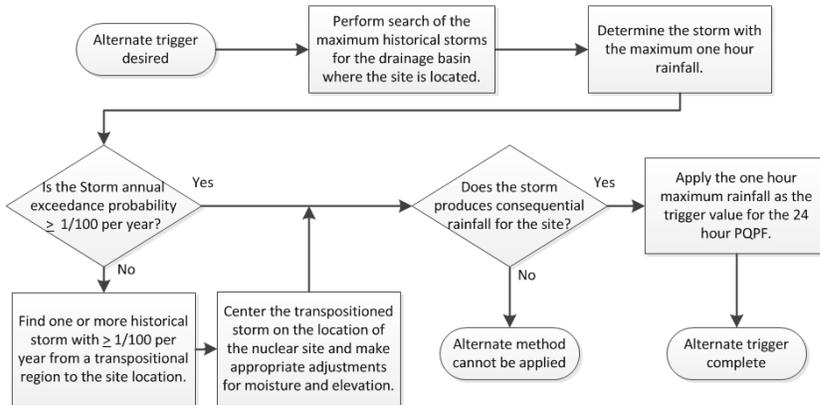


Figure 2. Alternate Action Trigger Flowchart

Other methods can also be used based on government and private forecasting models. Sites located within 50 miles of coastal areas should include monitoring of hurricane and tropical storm advisories from the National Hurricane Center in addition to the Weather Prediction Center precipitation forecasts. Plant sites west of the continental divide need to consider atmospheric river events where heavy bursts of rain can occur within an overall synoptic storm. An atmospheric river is a narrow corridor or filament of concentrated moisture in the atmosphere that develops along the boundaries between large areas of divergent surface air flow. These can occur from October through March, and can be a significant source of moisture and flooding.

A meteorologist should evaluate the nuclear site location to validate the acceptability of the monitoring threshold, trigger, and warning time based on the meteorological impacts of the local terrain and a review of weather history for the region associated with the nuclear site. The conservative bias of this approach increases the likelihood of false alarms. However, the consequence of a false alarm should be minimal assuming the trigger actions are limited to reversible actions such as securing doors/gates or staging equipment.

5.2.3 Forecast Accuracy Limitations: The accuracy of extreme rainfall forecast decreases as the projected levels exceed climatologically normal values and longer lead times. 24-hour precipitation values of 1/2 of the 1-hour LIP (e.g. 6"-9" from HMR-52) correspond to precipitation return rates on the order of 1/1000 (0.001 or 0.1%), or less, for most sites east of the 105th meridian. In Sukovich et al. 2014, Figure 6 shows a Probability of Detection for the WPC QPF forecasts of the top 0.1% of precipitation events near 0.25 (25%) for the CONUS (continental United States) in 2011. This qualitatively low level of detection is partially a function of the grading metric (full credit or no credit only), but is also a function of the inherent low bias that occurs when forecasting extreme events. The use of "1/2" of the 1 hour LIP or consequential event provides a level of conservatism intended to compensate for uncertainties in the precipitation forecast. Additionally, the use of the 24-hour 95th percentile PQPF as opposed to the QPF (comparable to the 50th percentile PQPF) builds in further conservatism to the methodology. The 95th percentile PQPF is designed such that an event has only a 5 percent chance of exceeding the forecast value, based on an ensemble of QPF model forecasts.

Comment [S24]: It is not clear whether this paragraph applies only to the alternate action trigger (which may be deleted) or more broadly. Should this be included in 5.2.2.A?

This document should clarify how the hurricane and tropical storm advisories will be used and whether 'coastal areas' applies to the Great Lakes.

Attachments:

Rev 4, 10-30-14

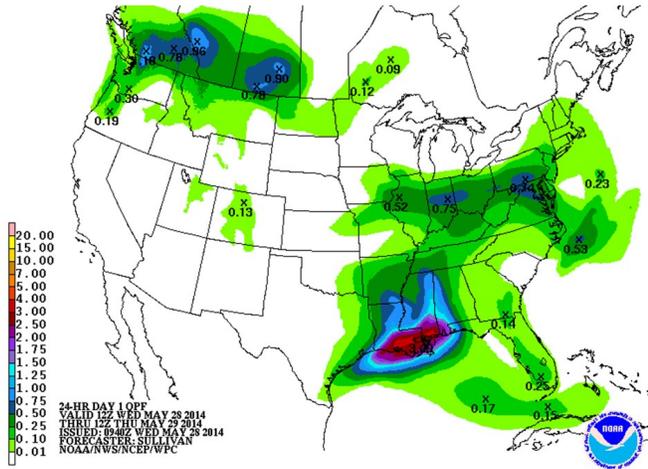
Attachment 1 - Probabilistic Quantitative Precipitation Forecast, Excessive Rainfall Outlooks

Attachment 2 - NWS Web Sites (Source Material), References

Attachment 1

Quantitative Precipitation Forecasts (QPFs) – EXAMPLE

(<http://www.hpc.ncep.noaa.gov/qpf/qpf2.shtml>)



Probabilistic Quantitative Precipitation Forecasts (PQPFs) – EXAMPLE

(http://www.hpc.ncep.noaa.gov/pPQPF/conus_hpc_percentile.php?fpd=24)

6-Hour Forecasts		24-Hour Forecasts	
Probability of Precipitation of at Least a Specific Amount	Precipitation Amount by Percentile	Probability of Precipitation of at Least a Specific Amount	Precipitation Amount by Percentile
24-Hour Percentile QPFs valid 12Z May 28, 2014 - 12Z May 29, 2014			
Percentile: <input type="radio"/> 5 th <input type="radio"/> 10 th <input type="radio"/> 25 th <input type="radio"/> 50 th <input type="radio"/> 75 th <input type="radio"/> 90 th <input checked="" type="radio"/> 95 th			
95 th percentile QPF for the 24-hour forecast valid 12Z May 28, 2014 - 12Z May 29, 2014			
<p>24-HR QPF EXPECTED NOT TO BE EXCEEDED WITH 95% PROB VALID 12Z WED MAY 28 2014 THRU 12Z THU MAY 29 2014 ISSUED 0940Z WED MAY 28 2014 WEATHER PREDICTION CENTER NOAA/NWS/NCEP/WPC</p>			
Viewing Options Choose a percentile for the specified time: <input type="radio"/> 5 th <input type="radio"/> 10 th <input type="radio"/> 25 th <input type="radio"/> 50 th <input type="radio"/> 75 th <input type="radio"/> 90 th <input checked="" type="radio"/> 95 th OR Choose a time for the specified percentile: <input type="radio"/> 12Z May 28 <input type="radio"/> 18Z May 28 <input type="radio"/> 00Z May 29 <input type="radio"/> 06Z May 29 <input checked="" type="radio"/> 12Z May 29 <input type="radio"/> 18Z May 29 <input type="radio"/> 00Z May 30 <input type="radio"/> 06Z May 30 <input type="radio"/> 12Z May 30 <input type="radio"/> 18Z May 30 <input type="radio"/> 00Z May 31 <input type="radio"/> 06Z May 31 <input type="radio"/> 12Z May 31			

Attachment 2

NWS Web Sites (Source Material)

NWS Weather Prediction Center (WPC)

<http://www.hpc.ncep.noaa.gov/html/fam2.shtml> - Website describing the WPC Products

<http://www.hpc.ncep.noaa.gov/index.shtml> - Website with QPC's and Excessive Rain Forecast

http://www.hpc.ncep.noaa.gov/pqpf/conus_hpc_percentile.php?fpd=24 – Website for Probabilistic QPF's

NWS National Hurricane Center (NHC)

<http://www.nhc.noaa.gov/> - Home page for NHC

NWS Storm Prediction Center (SPC)

<http://www.spc.noaa.gov/misc/aboutus.html>

<http://www.spc.noaa.gov/misc/about.html#Day 1 Convective Outlook>

NWS Weather Alerts

<http://alerts.weather.gov/>

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)¹
(includes recurrence intervals up to 1000 years and includes a 1 hour storm – listed by state)

<http://hdsc.nws.noaa.gov/hdsc/pfds/index.html>

NWS and Non-NWS listings of Weather Service Providers

<http://www.nws.noaa.gov/im/metdir.htm>

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4. Needham, H. and B. Keim (2014). "Correlating Storm Surge Heights with Tropical Cyclone Winds at and before Landfall." *Earth Interact.*, **18**, 1–26.
5. Ralph, F., E. Sukovich, D. Reynolds, M. Dettinger, S. Weagle, W. Clark, and P. J. Neiman (2010). "Assessment of Extreme Quantitative Precipitation Forecasts and Development of Regional Extreme Event Thresholds Using Data from HMT-2006 and COOP Observers." *J. Hydrometeor.*, **11**, 1286-1304.
6. Olson, D.A., N. Junker, and B. Korty (1995). "Evaluation of 33 Years of Quantitative Precipitation Forecasting at the NMC." *Wea. Forecasting*, **10**, 498-511.
7. Sukovich, E., F. Ralph, F. Barthold, D. Reynolds, and D. Novak, (2014). "Extreme Quantitative Precipitation Forecast Performance at the Weather Prediction Center from 2001 to 2011." *Wea. Forecasting*. doi:10.1175/WAF-D-13-00061.1, in press
8. J.T. Riedel and Louis C. Schreiner (1980). "Comparison of Generalized Estimates of Probable Maximum Precipitation With Greatest Observed Rainfalls ." NOAA Technical Report NWS 25, Hydrometeorological Branch, Water Management Information Division, Office of Hydrology, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Silver Spring, MD. March 1980, 1-2
9. J. Harrison, "Extreme Events: Graphs, Photos, Videos," in Dam Safety 2006: Proceedings of the 2006 Annual Conference of the Association of State Dam Safety Officials, Lexington, KY, September 10-14, 2006.

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